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Literature Review of the State of the Art for Graphical User Interfaces (GUI) for a Series of Oil Quality Monitoring Sensors for Shipboard Equipment

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Contract Number: W7707-088151/001/HAL
Contract Scientific Authority: R. Haggett, Project Authority, 902-427-3443

Defence R&D Canada – Atlantic

Contract Report
DRDC Atlantic CR 2009-058
March 2011

Canada

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Abstract

Over the past several years, DRDC Atlantic has embarked on a program for the evaluation of existing technologies, as well as the development of new technologies for application in platform specific lubricating oil condition monitoring systems. The current study is primarily focused on conducting a literature review of the current state of the art for graphical user interfaces (GUI) with general discussions of background technologies and potential frameworks for developing GUIs for oil condition monitoring systems.

The review indicated that various technologies are required to develop an effective GUI based condition based monitoring system. Technology requirements include: sensor technologies, data transmission options, data acquisition network design, GUI hardware options, GUI design, “Smart” systems, “Expert” system design, and data mining techniques. General discussions including various options within individual technologies with respect to developing an effective GUI based condition monitoring system have been included in the report.

Résumé

Au cours de ces dernières années, RDDC Atlantique a mené un programme visant l’évaluation de technologies existantes, ainsi que le développement de nouvelles technologies pour l’application de systèmes de contrôle de condition propres aux plates-formes. La présente étude se concentre sur une revue de la littérature sur l’état actuel de la technologie des interfaces graphiques (GUI) et comprend des discussions générales des technologies contextuelles et des cadres potentiels pour développer des GUI pour des systèmes de contrôle de condition d’huile.

La revue a indiqué qu’il faut diverses technologies pour développer un système de contrôle de condition efficace basé sur GUI. Les technologies requises comprennent : technologies de capteurs, options de transmission de données, conception d’un réseau d’acquisition de données, options matérielles de GUI, conception de GUI, systèmes « intelligents », conception de systèmes « experts » et techniques d’exploration de données. Des discussions générales portant sur diverses options à l’intérieur des technologies particulières en rapport avec le développement d’un système de contrôle de condition efficace basé sur GUI ont été incluses dans le rapport.

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Executive Summary

Literature Review of the State of the Art for Graphical User Interfaces (GUI) for a Series of Oil Quality Monitoring Sensors for Shipboard Equipment

K.J. KarisAllen; DRDC Atlantic CR 2009-058; Defence R&D Canada – Atlantic; March 2011.

Introduction: Over the past several years, DRDC Atlantic has embarked on a program for the evaluation of existing technologies, as well as the development of new technologies for application in platform specific lubricating oil condition monitoring systems. The current study, conducted by FACTS Engineering Inc., is primarily focused on conducting a literature review of the current state of the art for graphical user interfaces (GUI) with general discussions of background technologies and potential frameworks for developing GUIs for oil condition monitoring systems at DRDC Atlantic.

Results: The review indicated that various technologies are required to develop an effective GUI based condition based monitoring system. General discussions of technologies in the report include: sensor technologies, data transmission options, data acquisition network design, GUI hardware options, GUI design, “Smart” systems, “Expert “ systems, and data mining techniques. The diversity of technologies indicates that a highly integrated, multi-disciplinary approach should be adopted for the design and development of the system.

The diversity of technologies indicated that a highly integrated, multi-disciplinary approach should be adopted for the design and development of the system. Identified expertise required during the design and development phases included: sensor expertise, equipment expertise, sensor property experts, military requirement expertise, computer hardware specialist, database management experts, Expert systems specialists, and software programming expertise.

Future Work: A multi-phase development scheme has been proposed based on the modification of the existing systems currently available on the CPF platform. The phases include the definition of a general requirement, the conceptual design of the system, the development of an alpha prototype for evaluation at the fleet training center at HMC STADACONA, Halifax, and the development of a beta prototype for trial onboard a Canadian Patrol Frigate (CPF) platform.

Sommaire

Literature Review of the State of the Art for Graphical User Interfaces (GUI) for a Series of Oil Quality Monitoring Sensors for Shipboard Equipment

K.J. KarisAllen; DRDC Atlantic CR 2009-058; R & D pour la défense Canada – Atlantique; Mars 2011.

Introduction : Au cours de ces dernières années, RDDC Atlantique a mené un programme visant l'évaluation de technologies existantes, ainsi que le développement de nouvelles technologies pour l'application de systèmes de contrôle de condition propres aux plates-formes. La présente étude se concentre sur une revue de la littérature sur l'état actuel de la technologie des interfaces graphiques (GUI) et comprend des discussions générales des technologies contextuelles et des cadres potentiels pour développer des GUI pour des systèmes de contrôle de condition d'huile.

Résultats : La revue a indiqué qu'il faut diverses technologies pour développer un système de contrôle de condition efficace basé sur GUI. Les technologies discutées de façon générale dans le rapport comprennent : technologies de capteurs, options de transmission de données, conception d'un réseau d'acquisition de données, options matérielles de GUI, conception de GUI, systèmes « intelligents », conception de systèmes « experts » et techniques d'exploration de données. La diversité des technologies a indiqué qu'une approche multidisciplinaire fortement intégrée devrait être adoptée pour la conception et le développement du système

On a déterminé que les expertises requises pendant les phases de conception et de développement doivent comprendre : expertise des capteurs, expertise du matériel, expertise des propriétés des capteurs, expertise des exigences militaires, expertise du matériel informatique, expertise de la gestion des bases de données, expertise des systèmes « experts » et expertise de la programmation.

Recherches Futures : Un programme de développement en plusieurs phases a été proposé pour la modification des systèmes actuellement disponibles sur la plate-forme FPC. Les phases comprennent la définition d'un besoin général, la définition du concept du système, le développement d'un prototype Alpha pour fins d'évaluation au centre de formation de la flotte à HMC STADACONA (Halifax), et le développement d'un prototype Bêta pour fins d'essais à bord d'une FPC.

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1 Introduction

Condition based monitoring of structural and machinery components is currently being evaluated by various organizations for potential applications in automotive, industrial and military systems [1-8]. The potential benefits of condition based monitoring include reduced long-term maintenance cost, as well as the detection of system operating anomalies prior to the introduction of sustained component damage. In addition, dependent on the automation and inference structure associated with the monitoring system, the implementation of a condition based program may facilitate a reduction in the manpower required to adequately supervise and maintain in service equipment.

Over the past several years, DRDC Atlantic has embarked on a program for the evaluation of existing technologies, as well as the development of new technologies for application in platform specific condition monitoring systems. It has been envisioned that dedicated sensor, hardware, and software suites may be employed to provide engineering officers with real time monitoring with respect to the performance of critical ships' systems. The availability of real time equipment information facilitates the application of condition based maintenance regimes, as opposed to the historically employed time based maintenance approach. Potential ships' systems for monitoring include main machinery components, as well as critical load bearing members of the structural hull form. Identified general applications for dedicated monitoring systems include assessing the rheological properties of main machinery lubricants [9], detecting the ingress of water into high pressure hydraulic systems [10], conducting rotating machinery vibration analysis, and measuring structural strain [11]. The current study is primarily focused on conducting a literature review of the current state of the art for graphical user interfaces (GUI) with general discussions of background technologies and potential frameworks for developing GUIs for oil condition monitoring systems.

In general, methodologies for assessing the degradation/contamination sustained by main machinery lubricants or hydraulic oil can be divided into three broad categories: offsite analyses, onsite offline analyses, and online real-time analyses [12, 13]. In an offsite analysis, a relatively small quantity of oil is removed from the system and sent to a laboratory. Disadvantages of the offsite methodology include the time lag between sampling and assessment, the fluid analyzed may not be representative of the entire charge, and the potential for the introduction of error into the analysis owing to the sampling technique. While onsite, offline methodologies reduce the time lag between sampling and analysis, this methodology still contains the remaining drawbacks associated with offsite methodologies. Recently, several commercial ventures have been initiated for the development of inline sensors monitored by electronic hardware systems for the assessment of the rheological properties of various oils. These systems have the capability of providing a real-time assessment of the entire charge of oil to the lifecycle equipment manager, facilitating a proactive approach to predicting and troubleshooting potential problems.

The development of an effective application specific GUI requires an understanding of all the sensor/hardware/software components of the system. In general, a dedicated oil condition monitoring system is comprised of four main components (Figure 1). The first component is sensors which convert the parameters of interest to output signals capable of being measured. The majority of sensors are analog devices which are designed and manufactured to be property specific. Sensors are normally designed to convert the property into an electrical analog output

signal. The second component in the system is an electronic hardware package which inputs the analog output signal from the sensor and converts the signal into a standardized digital format (A/D conversion) for transmission to a microprocessor-based system. As is the case for many commercial sensors, the hardware may impose amplification and filtering on the input signal prior to the A/D conversion process. The third component in the system is a method of storing the digital signals, which also provides the algorithms for conducting any online post-processing required. Digital signals are normally routed to a microprocessor-based system which stores the data on a non-volatile medium. The software or firmware associated with the microprocessor can be configured to conduct the post-processing required for the specific application. The final component of the system is a graphical user interface (GUI). The GUI is the primary interface between the end user and the hardware/software functionality of the system. As such, the design and functionality of the GUI should be targeted towards the requirements and expertise of the end user. The information provided through the GUI should be easily accessed and presented in a manner that can be quickly interpreted by the user.

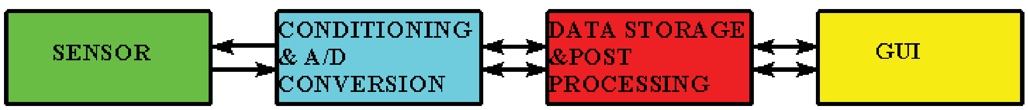

Figure 1: Schematic representation of the four main subcomponents associated with a health monitoring system.

The development of a realistic framework for an application specific real time condition monitoring system not only requires the knowledge of the options available for the GUI interface itself, but an understanding of the sensor technologies, signal conditioning, data transmission options, post processing hardware and software, data base structures, and the algorithms associated with Smart or Expert system design. The following sections provide general discussions of the options available for each sub-group.

2 Sensor Technologies

Parameters of interest with respect to assessing the condition of main machinery lubricants or hydraulic oil include system pressure (absolute and differential), temperature and viscosity. The formation or ingression contaminants may also degrade the rheological properties of the oil resulting in accelerated wear of rotating components such as bearings. Possible contaminants include coke, water (fresh and seawater), glycol, fuel dilution, and both ferrous and non-ferrous metallic wear debris particles. Recently, several ventures have been initiated for the evaluation and development of inline sensors monitored by electronic hardware systems for the assessment of the properties of various oils [14-26]. These systems have the capability of providing a real-time assessment of the entire charge of oil to the lifecycle equipment manager, facilitating a proactive approach to predicting and trouble-shooting potential problems. Proprietary sensor systems have been developed based on several oil properties including pH, conductance, relative dielectric constant, magnetic permeability, infrared transmission spectroscopy, X-Ray fluorescence spectroscopy, ferrography, and acoustic impedance. While many of these systems are still in the prototype development stage, systems have become available for evaluation. DRDC Atlantic has procured several inline prototype systems for evaluation which exploit changes in the complex permittivity of the lubricant, including a Lubrigard Oil Condition Sensor™ [27], an ANALEXrs Sensor™ [28], an EASZ-1 Sensor ™ [29] and a Schroeder TestMate TWS-C Sensor [30]. DRDC has also procured a prototype Sengenuity VISmart- ™ LSB2 sensor [31] designed to monitor the viscosity of oil using an acoustic impedance technique, and two commercially available debris sensors (an ANALEXrs Total Ferrous™ [32] and a GasTops MetalScan™ [33]). The following sections provide general discussions of several sensor technologies which have been exploited by DRDC to provide online information with respect to the presence of containments in lubricants.

2.1 Dielectric Sensors

Dielectric sensors monitor the changes in the complex permittivity of the lubricant. Two typical sensor configurations are commercially available. The first configuration is based on a solid state transducer where the changes in the complex permittivity of the contaminated transducer surface layer are monitored. The chemistry of the transducer can be chosen to respond either to a specific contaminant (such as water) or to a broad range of contaminants. Since the sensor response is predicated on the interaction of the transducer surface layer and the lubricant, only contaminants dissolved in the lubricant are typically detected (such as the percent water saturation for the Schroeder sensor evaluated by DRDC).

In the second configuration, changes in the complex permittivity of the bulk lubricant are monitored. In this configuration, the lubricant typically passes between two plates polarized using an AC signal, the frequency of which is specific to the contaminant of interest. In comparison to the solid state transducer configuration, this configuration is not limited to monitoring contaminants dissolved within the lubricant and can monitor suspended contaminants such as free water (EASZ-1 Sensor- ™).

2.2 Viscometers

Two types of available inline sensors are commercially available for the measurement of the viscosity of lubricants. The first type is an acoustic impedance viscometer which generates a fixed frequency acoustic signal within the lubricant using a solid state transducer. The energy required to generate the acoustic signal within the lubricant is dependent on the viscosity. Dedicated electronics measure energy losses (input minus output) associated with a solid state transducer as a function of oil viscosity. The combination of the unique properties associated with each transducer crystal and the non-linear relationship between energy loss and viscosity requires a specific calibration for each sensor transducer. In addition, since the sensor is essentially a force transducer, a minor dependence of measured viscosity on global system pressure may be observed.

The second type of sensor is a tuning fork transducer where the fork elements are excited at their resonance frequency. In this case, the attenuation of the cycle amplitude is correlated to the viscosity of the lubricant through a calibration function. Owing to the principle of operation, it has been indicated that possible sludge build-up around the sensor may generate a source of error in the bulk viscosity measurement. In addition, the presence of electrolytic contaminants within the oil may cause corrosion damage on the forks, which, in turn, changes the resonance frequency associated with the transducer.

2.3 Debris Sensors

In general, commercially available debris sensors utilize principles of magnetometry for the detection of metallic particles in lubricants. Alternating currents are typically routed through one or more primary coils to generate a stable magnetic field within the sensing chamber. Secondary coils positioned within the sensing chamber detect perturbations to the magnetic field resulting from the presence of metallic particles within the field. In the case of particle counting devices such as the GasTops MetalScan™, the passage of a ferrous particle through the chamber results in the modification of the amplitude of the sensing coil AC signal, whereas the passage of a non-ferrous particle results in a phase shift in the secondary coil signal. For submicron type sensors such as the ANALEXrs Total Ferrous™ device, quantification of the total ferrous debris within the sensing chamber is determined by comparison to a second identical, factory calibrated, reference chamber devoid of debris. As compared to a particle counting and sorting device, a total ferrous device provides a measure of the global volumetric presence of ferrous particles within the lubricant.

3 Data Transmission Options

While the means of conditioning, digitizing and transmitting the sensor signals does not directly affect the output from the GUI, it does affect the accuracy, precision, integrity, and security of the data being generated and displayed by the respective sensors. Two general transmission options exist for the design of the communication network associated with the condition monitoring system, namely, hardwired or wireless. For compartmentalized marine based platforms, there are benefits and disadvantages related to each option. As the name suggests, the primary benefit of wireless communication is the reduced wiring requirements of point to point transmission. Wireless communication is typically based on line of sight transmission where transceiver output power is typically selected based on the distance between communication points. For transmission within a compartmentalized, steel structure (such as a naval vessel) output power requirements will also be dependent on the number of decks and bulkheads between transmitter and receiver. Through bulkhead signal repeaters may be utilized to minimize the output power associated with communication within metallic structures. Data security and interference with other Radio Frequency (RF) based onboard systems require particular attention when including a wireless system on a military platform. Data security for RF systems is typically achieved by data encryption prior to transmission. Numerous protocols exist for the wireless transmission of data. Protocols commonly utilized by civilians and industry for data transmission applications include Bluetooth, Wi-Fi, ZigBee, etc.

Historically, communication within a naval vessel has been conducted through point to point hardwiring. The primary benefits associated with a hardwired system are data security and minimal potential for system to system interference. Data is transmitted over metallic conductors or fibre optic strands dependent on the distance between points, typical and atypical environmental considerations, and imposed electrical RF noise along the transmission path. While the integrity and security associated with a hardwire link is superior to an RF link, for military shipboard applications, access to available wires and conduits through watertight bulkheads tends to be limited. Wire runs through bulkheads to the sensors would also typically require the appropriate ship alteration approval procedures.

Output signal options for sensors may be analog, digital, or both. For sensors which generate an analog output signal (i.e. voltage or current loop), it is normal practice to close couple the conditioning and analog to digital conversion hardware to the sensor to minimize potential electrical and magnetic RF background noise in the signal. Once digitized, the digital data may be transmitted to the storage microprocessor via a hardwire link or an RF link. Digital data may be transmitted via parallel, synchronous serial and asynchronous serial protocols. Both parallel, synchronous serial protocols are typically employed for relatively short transmission distances due to the relationship between the timing constraints associated with the respective protocols and the transmission path electrical impedance. Numerous asynchronous serial protocols exist including RS232, RS485, USB, Ethernet, etc. Asynchronous serial communication facilitates data transmission over relatively long distances (in some cases, in the order of kilometres). The choice of protocol depends on whether single or multiple sensors will be connected to the same bus, as well as the data transmission rate required. It should be noted that some of the ultra high speed ethernet protocols are comparable to hard drive access times, making distributed computing a viable alternative to single platform based computing [34].

4 Discussion of Data Acquisition Networks

4.1 Description of the Current CPF Machinery Data Acquisition Network

Several standardized network designs are currently available for the acquisition and storage of the data generated by condition monitoring systems. Two commonly utilized designs are termed pyramid and token ring. For military systems, the choice of the design depends on the general specification requirements including; maintainability, reliability, redundancy, reconfiguration/ modification flexibility, and survivability.

As the name suggests, a pyramid network is a bottom up hierarchical structure where data availability is dependent on the operator responsibility at each level. An example case of a pyramid structure (Figure 2) is the network currently employed for data transmission on the Canadian Patrol Frigate (CPF). In this case, sensors associated with various machinery systems are hardwired to compartment based, remote-terminal units (RTU). The RTU acts as a transmission node for data signals (either analog or digital) from the various sensors. Several researchers have evaluated the feasibility of developing standardized, sensor-oriented, network interfaces [35-38]. The primary advantage of the standardized interfaces was the ease of integration of sensors into network systems which utilize the interface structures.

Signals from several compartment-based RTUs are bussed by hardwire to a dedicated hardware monitor located in the machinery control room (MCR). A PC-based enhanced programming interface has been added to the system at this level for generating and analysing data trends associated with individual sensors. Data from the MCR is, in turn, filtered and bussed to command and control which receives data from various ship's systems (i.e. machinery systems, combat systems, damage control, etc.).

One of the drawbacks of employing a hardwired pyramid network is that the failure of either a transmission node or a data bus line effectively precludes access of the upper hierarchical levels to the processes occurring at and below the point of the failure. A simple but plausible scenario is the case where an RTU or transmission line has been damaged between one of the compartments and the MCR. In this case, while the monitoring sensors are still actively collecting and transmitting data, the MCR and, by extension, command and control are not receiving the data for evaluation. While employing a hardwired token ring network would provide an alternative transmission path for the data, the requisite wiring would be considerable for a complex system such as a naval platform.

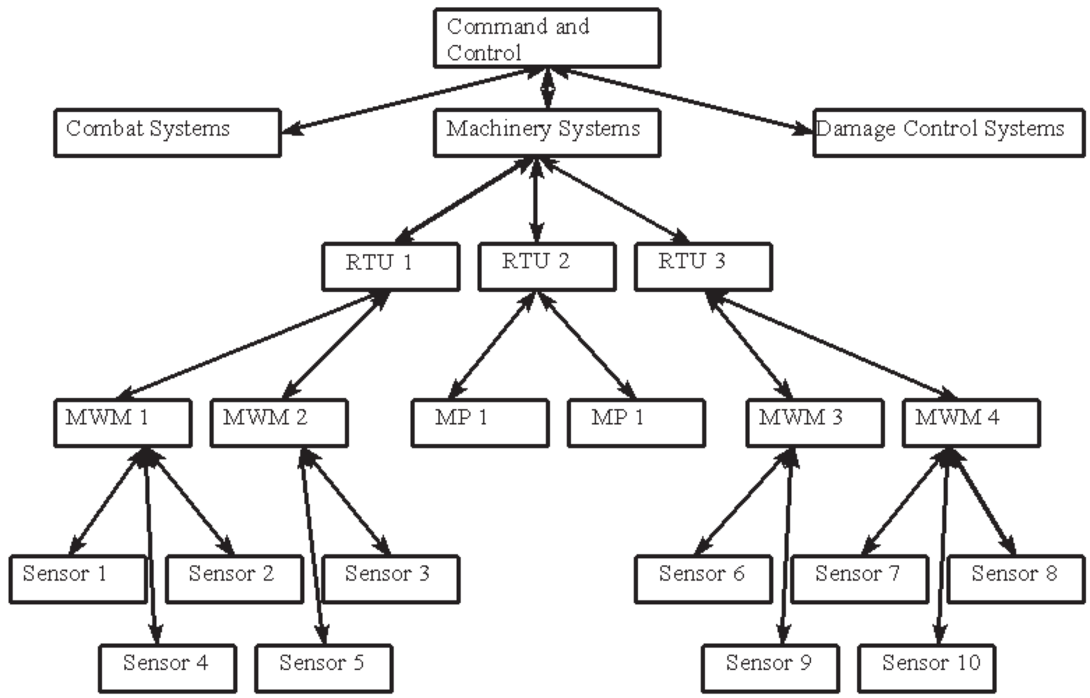

Figure 2: Schematic representation of the pyramid network structure currently employed for collecting data onboard the Canadian Patrol Frigate.

4.2 Advantages of a Wireless Data Transmission Network

Wireless networks provide a high degree of configuration as well as modification flexibility. For wireless systems, the sensor or data transmission node requires only a source of power. Owing to the absence of physical interconnections between nodes (i.e. wires), the function of individual nodes and the interrelationship between nodes is usually defined by software or firmware algorithms. Figure 3 shows a concept schematic of the advantages of utilizing a wireless network for configuring a bottom up network for data acquisition, combined with a top down network for operator interaction with the system. For this system, the sensor signals are digitized and bussed to transceivers which are close coupled to their respective machinery components, such as diesel generators, compressors, propulsion systems, etc. One or more wireless data transmission-repeater transceivers are located at strategically located positions within an individual compartment. Within the compartment, individual transmission/repeater transceivers may be programmed to acquire data from all the wireless sensors within the compartment or may be individually dedicated to a subgroup of wireless sensors. Owing to the close proximity of the sensor and transmission/repeater transceivers, transmission power can be minimized to reduce the

potential of a detectable signal at the exterior of the structure. Data transmission/repeater transceivers located in adjacent compartments are utilized to buss the data to one of several data servers located at strategic positions within the ship structure using a multi-hop protocol. One of the primary advantages of a wireless system using a multi-hop protocol is that the transmission path of the data is not fixed. In the event of the loss of individual transmission/repeater transceivers, the server may redefine the transmission path from the sensor in an automated, online fashion, which essentially generates a self healing transmission system.

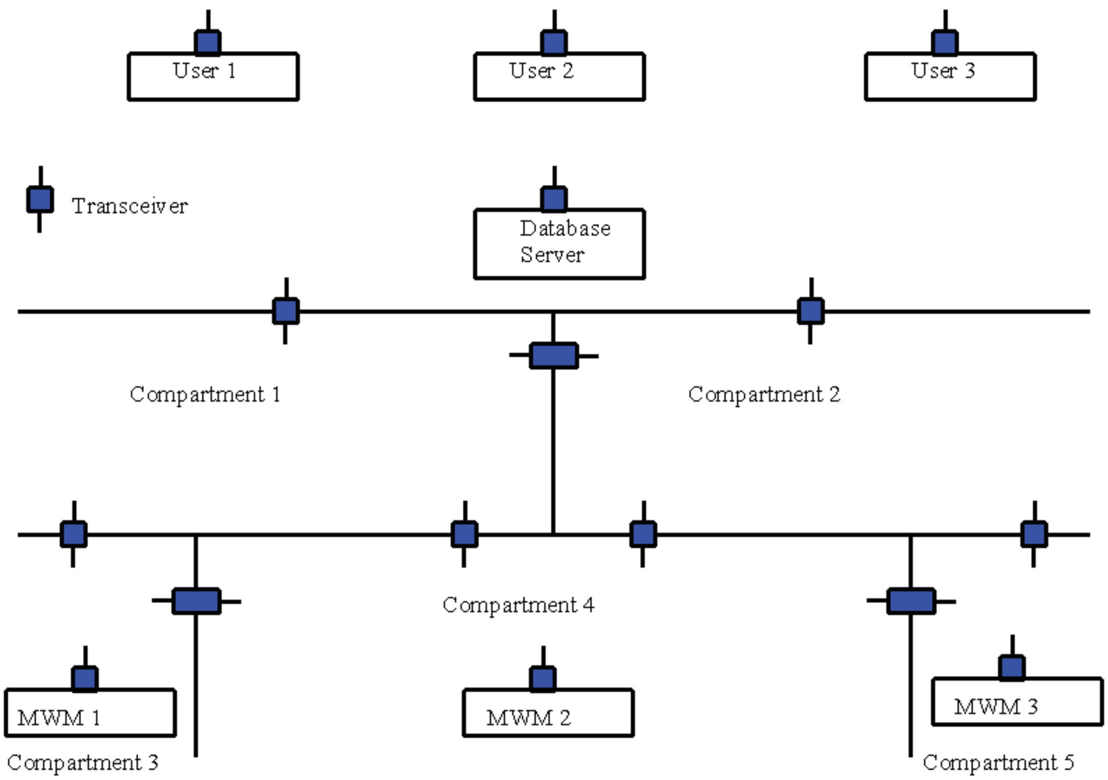

Figure 3: Concept schematic showing the potential advantages of utilizing a wireless network for data acquisition. The elimination of physical wiring facilitates the possibility of multiple data transmission paths to the database server (high level of redundancy).

The capacity of reliable, compact, non-volatile storage medium devices has increased to the point (in the order of terabytes) where mirror images of the entire ship data set can be stored on the servers associated with the system. Individual operators can connect to a server and interrogate the data base dependent on their individual requirement in much the same fashion as one currently connects to a website for specific information contained therein.

4.3 Database Structures

Several database structures exist for the storage of data generated by condition based monitoring. Commonly utilized data storage structures include sequential databases, relational databases, and object oriented databases. A sequential database, as the name implies, appends the data record received to the end of an existing file in the order it is received. Sequential databases may be either linear or non-linear dependent on the characteristics of the device (sensor) generating the data. In linear databases, the data is generated and saved with respect to some predefined increasing or decreasing parameter interval. For data sensors with integral A/D conversion hardware, the parameter is usually a predefined time interval. Locating specific records during post processing is typically achieved by opening the file for random access and offsetting the file pointer based on the initial record time stamp and digitizing time interval. One drawback of linear sequential structures is that for sensors that monitor parameters which are relatively constant for extended periods of time, the file size tends to increase without providing any significant additional information to the end user. One method for reducing the size of the database file while maintaining the usefulness of the data stored is to include algorithms at the storage site that save the incoming data record based on a change in the magnitude of the sensor parameter being monitored. In this case, the stored database file is non-linear in structure (with respect to time) and specific records cannot be accessed during post processing using the simple calculated offset procedure described previously. While sequential searching of the data records may be utilized, depending on the size of the file, the method is typically inefficient with respect to the demand on server resources. One commonly utilized methodology for locating records within a non-linear file of N records is referred to as a binary search. The technique initially samples the N/2 record to determine whether the value associated with the desired record is either greater or less than the N/2 value. If it is greater than the N/2 value, the algorithm samples the (N-N/2)/2 position for the next comparison. The algorithm continues to iterate until convergence to the desired value is achieved. The maximum number of iterations (i) required for convergence is $N/2^i = 1$ (i.e. the maximum number of iterations associated with a 4096 record file is 12). File indexing and hashing (where the data record is amenable) techniques have also been utilized to expedite the search process within non-linear file structures. While sequential data files provide an expeditious means of presenting data trends to the end user, manipulation of the record variables for determining the various sensor interrelationships (dependencies) tends to be programmatically cumbersome.

In relational databases (RDB), a series of tables are constructed to describe a physical process [39-41]. Each row in the table (tuple) is comprised of a structured set of fields (attributes) selected from a predefined set of values (domain). One or more attributes within each row are utilized to uniquely identify the row (key). Tables are constructed using a set of integrity rules or constraints dependent on the data manipulation language used to interrogate the tables. Additional tables are also generated describing the interrelationship between the attributes from two or more tables. The interrelationship is usually defined by procedures consistent with set theory algebra. The most commonly used data manipulation language is SQL (Structured Query Language). Databases generated using the integrity rules associated with a data manipulation language are highly portable between systems. While relational databases may be used to expeditiously generate the dependencies between sensor variables, the flexibility of the system is limited to query structures contained within the data manipulation language. In addition, there are physical systems which cannot be adequately modeled using relational databases.

The concept of object orientated databases (OODB) was developed to address the limitations associated with relational databases [42–44]. The tables in OODB are treated as objects with a user defined set of attributes. In comparison to relational databases, in addition to the basic variable type definitions, composite type definitions such as data structures and unions may also be included in the table attributes for OODB. Interrelationships between tables are typically defined through the respective attribute headers. The treatment of tables as objects also facilitates the development of data manipulation code which utilizes the power of various object orientated programming languages such as deep nesting, etc. While a considerable amount of work has been conducted by various companies in the development of OODB systems, at present, it could not be determined if a generic industry standard has been developed with respect to a basic specification governing database construction. As such, database portability between system platforms may be an issue.

5 General Discussion of Post Processing and Graphical User Interface Hardware

5.1 State of the Art for Graphical User Interface Hardware

The most common form of graphical user interface (GUI) hardware currently utilized is a monitor combined with a pointing device such as a mouse. The pointing device is used to select virtual objects on the monitor display which, in turn, instructs the microprocessor to execute a predefined set of commands. Single touch screens include the pointing device with the monitor hardware which detects electrical or thermal perturbations in the surface layer of the screen material as a means of pointing to a virtual object. Single touch screens have become common place in the retail industry as a time efficient means of conducting sales transactions. They are also commonly utilized for compact, portable, communication devices such as cell phones, etc. to include the increased functionality associated with the GUI while minimizing the size of the overall package. Recently, multi touch monitors have become available as a GUI interface. The advantage of multi touch monitors (over single touch monitors) is the ability to drive multiple concurrent pointing operations simultaneously in a single device. By extension, a multi touch monitor would facilitate multiple user interaction simultaneously on a single monitor. Researchers (such as Han et al. [45]) have developed demonstration applications which highlight the potential of multi touch monitors.

Prototype devices and concept designs for holographic imaging displays are currently receiving considerable attention as a possible next generation of GUI hardware devices [46]. The devices typically utilize a series of lasers to construct a 3-dimensional representation of the image. At present, however, direct interaction with the image by the end user is limited, resulting in application driven utilization of the technology.

Voice recognition hardware has also been utilized as a means of communicating with GUIs. The use of voice recognition as a primary interface has been limited; however, owing to reliability issues associated with the nuances between speech patterns of users. As such, voice recognition is typically employed as a single user interface which requires a degree of calibration for limited applications such as word processing.

Perhaps the most significant recent advances in commonly utilized GUI hardware have been developed by the entertainment gaming industry. Several companies (Microsoft, Sony, Nintendo, etc.) have developed dedicated hardware packages that provide a high degree of interactivity between the user and the GUI. The magnitude of the data streaming required in order to generate the pseudo real time response of the GUI is achieved using expanded data buss architectures (128 bit or better). To date, 128 bit buss architectures are not commonplace in personal computing devices (64 bit architectures are only starting to replace their 32 bit predecessors). Pointer devices utilized by the various gaming systems range from standard game controllers to sophisticated, multiple IR laser based pointer systems which monitor the relative displacement generated between individual pointers. In general, the hardware associated with gaming systems tends to support multiple simultaneous users. A demonstration of novel application of the utilization of the IR laser based pointer hardware developed for a gaming system in personal computing GUI manipulation has been provided by Lee et al. [47].

5.2 Graphical User Interface Design

The GUI is typically comprised of a number of graphical objects which; when selected, execute a series of data post processing algorithms and displays a result back to the user. In a well designed GUI, most of the calculation and decision making processes remain transparent to the end user. An example of a relatively basic oil condition monitoring GUI developed for shipboard personnel is shown in Figure 4. The GUI contains several virtual gauge indicators that display various process parameters and alarm states. The GUI also provides historical data to the end user via a custom designed virtual strip chart recorder. While basic in utility, the GUI highlights the primary components of GUI construction.

Several methods of creating the virtual instruments utilized by condition monitoring systems are available to the software developer. Instruments can be either custom designed and hard coded into the program using graphics primitives available in the primary programming language (such as those developed in C++ in Figure 4), or they can be developed using specialized external software programs and ported into the program during compilation and execution of the program (as is the case with Active X controls).

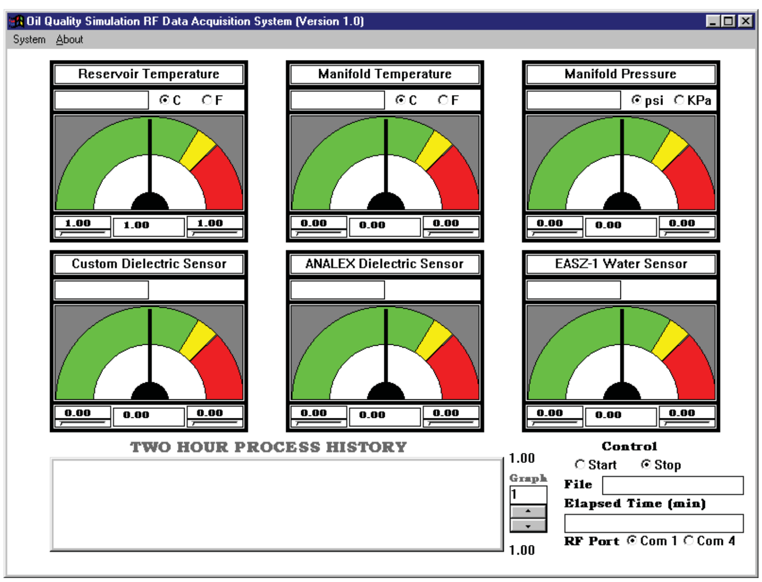

Figure 4: Bitmap of a relatively basic oil condition monitoring GUI developed for shipboard personnel.

The (GUI) is typically the main interface, and sometimes the only interface, between the user and the functionality of the system. As such, the design and operation of the GUI must be consistent with both the requirements and the level of expertise of the end user. For example, an oil condition monitoring GUI designed for shipboard personnel would differ from that designed for a system lifecycle maintenance manager (LCMM) which would differ again from that designed for a lubricant expert. Designing and developing an effective oil condition monitoring system would require input from all of the above mentioned parties as well as selected external parties.

Operation of the condition monitoring system would also require a significant degree of ongoing communications between the parties.

Within the shipboard environment, personnel requirements of the GUI may vary depending on the task requirements associated at each level of responsibility. At the stoker level, simple virtual gauges which indicate that the motor is operating within normal operating intervals may suffice. At the MCR level, in addition to displaying the real time data associated with the sensors, the GUI should provide a means of displaying data trends to the operator, and by evaluating the trends, provide predictions with respect to when normal maintenance of the motor is required (ie when to change the oil, etc). The GUI at the MCR level should also be able to detect and flag abnormal magnitudes or trends in the data. Background algorithms should be incorporated into the GUI for evaluating the source of the abnormality and providing the appropriate remedial action. Evaluation algorithms should include Expert System decision matrices as well as various database mining techniques. At the Engineering Officer/Command and Control level, the attributes of the GUI should highlight abnormal conditions and predicted outcomes. At this level, the GUI should also indicate any other equipment which may be affected by the outcome, as well as how the outcome may affect the availability of other ship's systems (i.e. combat systems, damage control, etc.). A means of sending the information associated with the abnormal condition to the LCMM (including supporting sensor data) should also be included at this level.

One of the tasks of the LCMM is to monitor the operational status of the equipment and systems within their area of responsibility. Thus, based on information generated by the fleet, the GUI at the LCMM level should incorporate algorithms to evaluate specific shipboard abnormalities, as well as be capable of correlating the abnormalities to similar occurrences either on a platform, class or for the entire fleet bases. Where prior occurrences of the abnormality have been logged in the database, the short and long term implications of postponing the recommended remedial action should be highlighted based on past experience. At the LCCM's discretion, the GUI should be capable of initiating specific shipboard, class, or fleet directives based on the outcomes predicted by the GUI algorithms.

The features associated with the GUI designed for a lubricant expert should contain all the algorithms previously mentioned for shipboard personnel and the LCMM. In addition, the GUI should be able to interrogate the database to ensure proper functionality of the sensors, hardware, and software components of individual shipboard systems. The GUI should also incorporate the means of altering any of the Expert System decision matrices using the modified decision tree, and conduct "what if" analyses on the existing database in order to compare the predicted outcomes.

6 Discussion of Smart and Expert Systems

6.1 General Attributes of Smart Systems

Smart systems are generally implemented by developing a series of deterministic algorithms which process input data using a fixed logic sequence using conventional programming techniques [48-52] and compilers (i.e. C++, Fortran, etc). The programs are typically utilized for conducting numerical calculations on relatively large, numerically based databases. The fixed logic sequence of the algorithms suggests that for a given database input, the outcome will also be fixed. User interaction with Smart systems also tends to be fixed and relatively limited.

Smart algorithms may be utilized to increase the level of sophistication of the GUI by including a predictive capacity; for example, GUI systems which include background algorithms that combine current process sensor values and historical data trends which, in turn, predict an outcome fall within the category of Smart systems. With respect to a lubricant condition monitoring system, while Smart algorithms may predict “when” a particular outcome may occur, they typically do not indicate “why” the outcome is occurring or the nature of the driving force behind the outcome. As such, one of the common utilities of Smart systems is for the generation of system maintenance schedules.

One example of an algorithm that would be classified as Smart would be to fit a function to the trends observed in historical data generated by the dielectric and viscometer sensors incorporated into the system. Based on the respective current values, dedicated algorithms may be utilized to predict the time line associated with when the lubricant properties no longer meet the operational specification and require replacement.

A second example of a Smart algorithm is the assessment of the current mass rate and particle size distribution as monitored by a metallic debris sensor. The generation of high mass rates in combination with relatively large particle sizes may indicate the imminent failure of a system bearing. The location of the sensor combined with further classification of the debris generated as ferrous or non-ferrous by the sensor may provide maintenance personnel with a reduced set of bearings requiring inspection prior to reactivation of the system.

6.2 General Attributes of Expert Systems

In comparison to Smart systems, Expert systems utilize a heuristic approach in the development of the program structure [53-58]. The primary goal of an Expert system is the replication of the cognitive thought process by a specialist in the field of interest. The foundation of an Expert system is a symbolically structured knowledge base. Symbolic programming languages such as LISP and PROLOG are commonly utilized in the development of Expert systems. Expert systems tend to be highly interactive in nature and; as such, require significantly more training by the end user. Expert systems typically present the user with a series of queries, the response to which may result in additional queries by the software. The means of evaluating and modifying the knowledge base must also be included with the system. “Adaptive” algorithms are usually included with Expert systems to modify the knowledge base and decision matrices based on

verifiable information (such as a laboratory analysis conducted on a time stamped lubricant sample).

Expert GUI systems typically include complex decision matrix algorithms (both deterministic and probabilistic) which are based on inferences generated by experts in the field (in this case, lubricant properties). The input to the decision matrix may be the output analysis from one or several parameter sensors generated by Smart systems as described previously. Expert systems are typically designed to provide direction with respect to the “why” and “what” is causing the observed outcome.

One application of an Expert system in an oil conditioning system is the determination of the probable cause of an activated alarm indicator associated with one of the sensors. By way of example, a possible decision matrix tree for the case where the viscometer high alarm was indicating an increase in lubricant viscosity in an engine with a closed-loop, fresh water cooling system is given as:

Initial Observation – Increase in the viscosity of the lubricant.

Possibilities 1 - 1) General carbon thickening of the oil.

2) Ingress of water into the oil.

System Query 1 – Are lubricant dielectric and conductance sensors installed?

Answer 1 – Yes.

Action 1 - Check engine lubricant dielectric and conductance sensor histories.

Observation 1 – Relatively high rate of increase in the permittivity and conductance noted just prior to the viscometer alarm.

Possibilities 2 – 1) Seawater ingression into the lubricant.

2) Ingression of an alternative conductive contaminant into the lubricant.

System Query 2 – Is a coolant conductance sensor installed?

Answer 2 – Yes.

Action 2 - Check engine coolant conductance sensor history.

Observation 2 – Gradual increase in the conductance started approximately 6 months prior to the viscometer alarm.

End Response – High probability of leak in seawater to fresh water exchanger.

Recommended Remedial Action – Blow down exchanger, plug leaking tube and refill with demineralised water. Check engine coolant seals.

6.3 Data Mining Techniques

Data mining is the science of interrogating historical databases to leverage the information associated with either a known or desired outcome. Data mining is a form of computational statistics which identifies patterns in data sets and provides either known or unknown correlations between the patterns generated. The correlations can, in turn, be utilized in predictive models for linking cause and effect scenarios. The technique is heavily utilized by the financial, retail, and marketing sectors. By way of example, in the marketing sector, large databases are collected and mined with respect to consumer spending habits, preferences and trends, the results of which are utilized to develop marketing and advertizing strategies to promote various products.

Several techniques are utilized for the generation of the correlations used as predictive indicators of an outcome [59-60]. Brief descriptions of common techniques used include:

1) Regression Analyses - Statistical regression analyses are used in data mining to establish correlations (relationships) between the sensor variables in the database. The analyses may be single or multi-variant which establishes either linear or non-linear relationships. Weighted functions are also commonly employed.

2) Neighbourhood Analyses – The neighbourhood analyses technique uses the immediately prior variable samples to predict (or test) the outcome of the next or subsequent samples.

3) Clustering Analyses – Clustering analyses group the data from similar components together (such as all the diesel generators in the CPF fleet) and analyse the data for general relationships.

4) Decision Tree Analyses – Generates a set of rules which governs the relationships and predictors generated in items 1-3. Decision tree analyses are generally used to refine the information generated by other techniques and typically require input from an expert in the field.

The correlations and predictive inferences generated using past history data mining techniques is one commonly utilized methodology for training the neural networks typically associated with Expert systems. The method is commonly referred to as "reverse training" and is a means of establishing relationships and dependencies which exist between the various sensor variables within the system. By way of example, consider the scenario described in the previous section. Mining of the database associated with the condition monitoring system would establish a relationship between the gradual increases in coolant conductance six months prior to the observed increase in lubricant viscosity. Training the system using the relationship would result in a predictor which upon subsequent detection of an increase in coolant would predict that an increase in lubricant viscosity will occur in the future. It should be noted that training the system in this manner does not provide the reasons the two observations occurred, which is the task of the cognitive algorithms associated with the Expert system.

7 Discussion of General Frameworks for Oil Condition Monitoring Systems

7.1 Description of the Expertise Requirements Associated with the Development of an Equipment Monitoring System

The general discussions in the previous sections indicate that the development of an effective GUI based condition monitoring system targeted for shipboard equipment applications requires a highly integrated, multi-disciplinary approach. The expertise requirements identified together with a brief description of function have been summarized in Table 1. The complexity of the task associated with the development of the system suggests that experts should maintain regular interaction.

Table 1: Summary of expertise requirements associated with the development of a condition monitoring system.

Expertise	**Function**
Sensor Expert	The function of the sensor expert is the evaluation and selection of the sensor requirements for the system. The sensor expert should provide the interface between sensor property expert and the OEM manufacturers of the various sensors.
Equipment Expert	The primary function of the equipment expert is the selection of equipment locations where sensor may be integrated into the system. Sources of expertise include the LCMM, fleet maintenance personnel, shipboard personnel, as well as the OEM manufacturers of the various equipment systems.
Sensor Property Expert	The function of the sensor property expert is to identify property parameters where, if included in an online data acquisition and management system would provide benefit with respect to maintaining and resolving issues pertaining to fleet equipment.
Military Requirement Expert	The function of the military requirement expert is the selection equipment (based on past operational availability or maintenance cost) which may benefit from the incorporation of an online monitoring system. Sources of expertise include the LCMM, fleet maintenance personnel, shipboard personnel, as well as the fleet command structure.

Computer Hardware Expert	The function of the computer hardware expert is the selection of the computer based hardware for the system. Hardware includes microprocessors, displays, storage mediums and capacities, as well as networking hardware and protocols. System requirements should be selected based on maintainability, reliability, redundancy, reconfiguration flexibility, and survivability.
Database Management Expert	The primary function of the database management expert is the design of the database file structures (i.e. sequential, relational, or object orientated).
Expert System Designer	The function of the Expert system designer is developing the framework definition for the neural networks associated with the system. The Expert system designer will also be responsible for the definition of the data mining techniques relevant to the system.
Computer Software Programming Expert	The function of the software programming expert is multi-fold. The programmer will develop the backbone of the system including algorithms for sensor to network communication, server to server communication, GUI component development, data mining procedures, as well as Smart and Expert system software components.

7.2 Development of an Equipment Monitoring System

The following section provides the general procedural requirements associated with the development of a condition monitoring system. For the purpose of this discussion, the steps required to reconfigure and include a condition monitoring system for the machinery components supervised by the MCR onboard CPF will be utilized as a point of reference. A working group should be established to supervise all phases of the project.

The procedure is a multi-phase process with the initial phase being the determination of the general system requirements. The determination of the system requirements should include military personnel, machinery system’s maintenance managers, and fleet support expertise (lubricant experts, etc.). Topics for review should include:

1) The identification and cataloguing of the machinery systems (and subsystems) currently supervised by the MCR.

2) An evaluation of the historical problems associated with the various machinery systems.

3) General and specific deficiencies identified in the current supervisory system, including additional machinery components which require some level of supervision, as well as installing additional sensors in components currently being monitored.

4) Development of the general specification requirements for the system. The specification should include the level of post processing required (i.e. simple monitoring, inclusion of Smart algorithms for generating maintenance schedules, Expert system algorithms for evaluating abnormal conditions, etc.).

The second phase of the project is the initial concept design for the system. The initial concept design should include:

1) The detailed specifications associated with the current monitoring system. For each machinery system, the sensor specifications should include: sensors installed, sensor functionality (mechanical or electronic), communication protocol (analog or digital signal if electronic), and any sub-system interface protocols to the RTU within each compartment. The number and characteristics of any non-utilized expansion ports on the individual RTUs should also be noted, as well as the specifications associated with various RTU network protocols to the main console in the MCR.

2) Additional sensors proposed for each machinery system currently being supervised. Each sensor proposed should be evaluated with respect to suitability for the proposed function, reliability based on either a DND assessment or proven field applications by the vendor, initial availability and lead times associated with replacement, etc.

3) Characteristics of the communication interface between the additional sensors and the RTU (i.e. hardwired or wireless).

4) Proposed database structures and implementation. The database structure requirements will be contingent on the post-processing requirements as determined in the initial phase of the project (i.e. simple monitoring, Smart algorithms, or Expert algorithms). One relatively non-intrusive means of generating the databases without significantly impacting the performance characteristics of the current system is by inserting a series of transparent, flow-through, asynchronous, hardware ports between the various RTUs and the main console in the MCR. In this configuration, signals may be tapped and bussed to a server for database generation and maintenance.

5) The detailed specifications for the microprocessor based hardware including, processor requirements, RAM, non-volatile storage, GUI display characteristics, and user interaction devices.

6) The detailed specifications for the software requirements of the system including the GUI constructs, network management algorithms, database management algorithms, real-time data monitoring algorithms, Smart and Expert systems algorithms, and data mining algorithms.

Once a concept design has been completed, the overall design should be reviewed by the working group for evaluation against the general specification requirements determined in the initial phase of the project. Upon completion of the review process, a working system (alpha prototype) may be developed for evaluation. It is suggested that the fleet training center located within HMC STADACONA in Halifax may be an ideal site for the evaluation of the alpha prototype system. Upon successful completion of the evaluation and modification processes, a beta prototype system may be developed for trial on an operational platform. It is suggested that one of the last CPF platforms currently scheduled for a mid-life refit may be an ideal candidate for the evaluation of the beta prototype. It is envisioned that the overall performance evaluation generated during the shipboard trial be utilized in the design and configuration of the final design which may potentially be implemented in post refit platforms.

8 SUMMARY

Over the past several years, DRDC Atlantic has embarked on a program for the evaluation of existing technologies, as well as the development of new technologies for application in platform specific health monitoring systems. It has been envisioned that dedicated sensor, hardware, and software suites may be employed to provide engineering officers with real time monitoring with respect to the performance of critical ships' systems. The current study is primarily focused on conducting a literature review of the current state of the art for graphical user interfaces (GUI) with general discussions of background technologies and potential frameworks for developing GUIs for oil condition monitoring systems.

The review indicated that various technologies are required to develop an effective GUI-based condition based monitoring system. Technology requirements include: sensor technologies, data transmission options, data acquisition network design, GUI hardware options, GUI design, Smart systems, Expert system design, and data mining techniques. General discussions including various options within individual technologies with respect to developing an effective GUI based condition monitoring system have been included in the report.

The diversity of technologies indicates that a highly integrated, multi-disciplinary approach should be adopted for the design and development of the system. Identified expertise required during the design and development phases includes: sensor expertise, equipment expertise, sensor property experts, military requirement expertise, computer hardware specialist, database management experts, Expert systems specialists, and software programming expertise.

A multi-phase development scheme has been proposed based on the modification of the existing systems currently available on the CPF platform. The phases include the definition of a general requirement, the conceptual design of the system, the development of an alpha prototype for evaluation at the fleet training center at HMC STADACONA, Halifax, and the development of a beta prototype for trial onboard a CPF platform.

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List of symbols/abbreviations/acronyms/initialisms

AC	Alternating Current
A/D	Analog to Digital
CF	Canadian Forces
CPF	Canadian Patrol Frigate
CPU	Central Processing Unit
DND	Department of National Defence
DRDC	Defence Research & Development Canada
EO	Engineering Officer
GUI	Graphical User Interface
IR	Infrared
LCMM	Life Cycle Maintenance Manager
MCR	Machinery Control Room
OEM	Original Equipment Manufacturer
OODB	Object Oriented Database
PC	Personal Computer
RAM	Random Access Memory
RDB	Relational Database
R&D	Research & Development
RF	Radio Frequency
RTU	Remote Terminal Unit
SQL	Structured Query Language

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Over the past several years, DRDC Atlantic has embarked on a program for the evaluation of existing technologies, as well as the development of new technologies for application in platform specific lubricating oil condition monitoring systems. The current study is primarily focused on conducting a literature review of the current state of the art for graphical user interfaces (GUI) with general discussions of background technologies and potential frameworks for developing GUIs for oil condition monitoring systems.

The review indicated that various technologies are required to develop an effective GUI based condition based monitoring system. Technology requirements include: sensor technologies, data transmission options, data acquisition network design, GUI hardware options, GUI design, “Smart” systems, “Expert” system design, and data mining techniques. General discussions including various options within individual technologies with respect to developing an effective GUI based condition monitoring system have been included in the report.

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Oil condition monitoring

Graphical user interface

GUI

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